Impact of diluted Red Sea water, irrigation frequency and organic mulch on Millet and Sorghum growth in a sandy soil

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DIDICATION

To my father

To my mother

To my sisters and brothers

To my dear friends and colleagues

Mohamed

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Abstract

This study was undertaken to simulate the growth of millet and sorghum in the loamy sand soils in the Red Sea coast using mixed sea-khor water. Tap water was used. In the first season, the treatments consisted of: five water salinity levels; namely, 0.4 (tap water), 3.1, 5.5, 9.3, and 16.6 dS/m, three irrigation intervals; namely 2, 4 and 7 days, presence or absence of an organic mulch, one crop millet and three replicates. In the second season the treatments consisted of four water salinity levels; namely, 0.4 (tap water), 3.1, 5.5, and 9.3 dS/m, three sorghum varieties; namely Aklomoy, Wad Ahmed and R5, four replications and one irrigation interval (2 days). In both seasons the pots were arranged in completely randomized design. The quantity of irrigation water was estimated by computing monthly reference evapotranspiration from long-term meteorological data using Jensen equation, monthly crop coefficient using the FAO method and leaching fraction that varies with the salinity of the irrigation water. The impact of the electrical conductivity of the irrigation water (ECi), irrigation interval, mulching, crop variety on germination and plant height was studied.

For all crops, the results showed significant ($P < 0.001$) linear increase in germination percentage (G %) with increase in time (Td, days) at all salinity levels of the irrigation water (ECi). However, germination was delayed for two and three days when millet was irrigated with mixed waters having ECi equal to 9.3 and 16.6 dS/m, respectively. Generally germination was delayed by high water salinity. The degree of tolerance of the various crop varieties at the germination stage was found to be in the following order:

Wad Ahmed > Millet > R5 > Aklomoy

The results showed significant quadratic decrease in millet height with increase of ECi. The order of crop salinity tolerance three weeks after germination was found to be different from the order at germination.

ملخص الاطروحة

أجريت هذه الدراسة لمقارنة نمو محصول الدخن والذرة فى ترب الطفل الرملى بساحل البحر الاحمر، وذلك باستخدام مياه الخيران (مياه الشرب) ممزوجه بمياه البحر.

فى الموسم الاول كونت المعاملات من خمسة مستويات ملوحة ماء: 0.4 (مياه الشرب) ، 3.1، 5.5، 9.3 و 16.6 ديسيسيمان/م. ثلاث فترات رى : يومين، اربعة ايام و أسبوع ، فى وجود او غياب التغطية العضوية وذلك لمحصول الدخن بثلاث مكررات.

فى الموسم الثانى احتوت المعاملة على اربع مستويات ماء مالح هى: 0.4 (مياه الشرب) ، 3.1، 5.5 و 9.3 ديسيسيمان/م. وثلاث انواع من محصول الذرة (اكلوموى، ود احمد و R5) باربع مكررات و فترة رى واحدة (يومان).

فى كل من الموسمين رتبت الاحص بالتصميم كامل العشوائية. تم تقدير كمية مياه الرى باستخدام طريقة حساب البخر نتح الشهرى من بيانات الارصاد الجوى لمدة زمنية طويلة باستخدام معادلة Jensen ، معاملات الحصول الشهرى باستخدام طريقة الفاو والغسيل الجزئى الذى يختلف باختلاف ملوحة ماء الرى. تمت دراسة أثر التوصيل الكهربى لمياه الرى (ECi) ، فترة الرى ، التغطية ، انبات صنف المحصول وارتفاع المحصول.

أظهرت النتائج فى كل المحاصيل زياده خطية معنوية ($P < 0.001$) فى النسبة المئوية للانبات بزيادة الزمن (Td) فى كل مستويات الملوحة لمياة الرى (ECi) . ومن ناحيه اخرى تأخر الانبات يومان و ثلاثة ايام عند الرى بمستوى ملوحة 9.3 و 16.6 ديسيسيمان/م على التوالى. بصورة عامة تاخر الانبات باستخدام مياه عالية الملوحة.

وجد ان درجة تحمل الانواع المختلفة من المحاصيل للملوحة فى مرحلة الانبات بالترتيب كالاتى:

ود احمد > الدخن > R5 > أكلوموى .

أظهرت النتائج انخفاضا معنويا من الدرجة الثانية فى ارتفاع الدخن مع زيادة التوصيل الكهربى. وجد ان ترتيب تحمل المحاصيل للملوحة بعد ثلاث اسابيع من الانبات مختلفا عن ترتيبها عند الانبات.

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Chapter One

Introduction

Sudan is a large country (2.5×10^6 km^2) dominated by arid and semi-arid tropical regions that favor the formation of salt-affected soils. Highly saline soils occur where the average annual rainfall is less than 200 mm. In most soils average salinity tends to increase with depth (Mustafa, 1986). The Red Sea State is characterized by a dry arid environment where good quality water is limited. The State is seriously affected by desertification. The people in this State suffer from poverty, hunger and malnutrition, rain and underground water shortage. The water of the Red Sea is highly saline and not suitable for irrigating field crops. The State depends on Khor Arbaat and ground water resources for growing field crops. Because of the limited rainfall, the annual recharge of the ground water is limited, and its quality is deteriorating. The decreasing availability of fresh water for agricultural use is a problem common to many areas in the world. Drought and salinity are the most important problems responsible for crop yield losses in arid and semi-arid regions. In North Africa and the Arab Gulf countries with limited good quality water resources, high salinity water is used for irrigating sandy soils. Some research was conducted in USA on the use of high salinity water mixed with good quality water for reclaiming salt-affected soils and for growing salt-tolerant field crops.

Millions of hectares of land throughout the World are too saline to produce acceptable crop yields, and more land becomes non-productive each year because of salt accumulation. The accumulation of soluble salts in these lands imposes a stress on growing crops that can result in yield reduction and, in severe cases, complete crop-failure. Direct or indirect expansion of salt-affected soils is one of the major constraints of crop production in arid and semi-arid regions of the world. Such soils cover large tracts of lands in North Africa, Australia, Mexico and southeast of the United States (Sanchez, 1976; Greenland, 1977).

In arid and semi-arid regions, one third of the agricultural land is thought to be affected by salinity to some degree (Allison, 1964). Salinity problems in agriculture are usually confined to arid and semi-arid regions where rainfall is not sufficient to leach salts out of the plant root zone.

Seawater cannot be used for drinking but may be suitable for irrigated agriculture in coastal areas. Indeed, seawater irrigation of halophytes offers an opportunity to bring these lands under agricultural production. However, the salinity of seawater exceeds the limit tolerated by conventional crop plants (Glenn *et al.*, 1993). Halophytes are plants that grow naturally in saline environment, such as salt marsh, salt pans and salt deserts (Jefferies, 1981). In recent years, it has been demonstrated that revegetation of saline habitats with halophytic species is profitable, and provides many additional benefits as they can be used for fodder, fuel, oil, wood or fiber production. They can also be used for land reclamation, dune stabilization, or as ornamental plants (Lieth and Masoum, 1993).

There are some 32000 km of sandy coastal lands, which are unused for agriculture, and could be brought under cultivation using a variety of conceivable aqua-agro-system in littoral, tidal and estuarine zones, by appropriate new methods of agro-management (Aronson, 1986).

There is little work in the Sudan on irrigation using seawater although there are many attempts in this respect abroad (Epstein *et al.*, 1980; ICBA 2004). The Red Sea coastal fringe is dissected by seasonal streams (khors) that drain into the Red Sea after heavy rains (Sulaiman and Musa, 1989). The beds and banks of these khors provide opportunities for the high soil salinities of the salt marsh to be reduced by fresh water thus encourages special vegetation types that normally do not occur under salinity stresses of salt marsh (Ali and Mohamed , 1991).

Because fresh water is scarce especially in the Red Sea area where rainfall is not sufficient to support plant growth, there is need to explore the possibility of growing salt-tolerant crop using seawater-freshwater mixtures. To our knowledge there is paucity of research in this area. Thus, the present study was undertaken, to achieve the following specific objectives:

- Study the effect of salinity level in the mixed sea-khor or/ well waters for growth of selected field crops.
- Investigate the impact of irrigation frequency and mixed sea and tap water at different ratios on millet and sorghum growth.
- Investigate the interaction between salinity and irrigation frequency.
- Investigate the impact of salinity and irrigation frequency on water use efficiency.

Chapter two

Literature Review

2.1 Definition of Desertification

Desertification is defined as land degradation in arid, semi-arid and dry sub-humid areas, resulting from various factors, including climatic variation and human activities (UNCCD 1994).

The main characteristic of the arid regions is that they have low erratic rainfall, which is less than the potential evapotranspiration during most months of the year (Salih, 1996). This is one of the major reasons for the occurrence of salinity in arid regions. Salinity in agricultural land is usually confined to arid and semi-arid regions where rainfall is not adequate to leach salts from the plant root zone (Al-Jaloud and Hussain, 2004). Salinity has been shown to affect the time and rate of germination, the size of plant, branching, leaf size, and over all plant anatomy (Poljakoff-Mayber and Gale, 1975).

2.2 Salinization as a desertification process

Salinization is the increase of the total soluble salt concentration in the root zone of the soil profile. If salinization is not checked, it will result in the formation of saline soils, which are more extensive in the arid and semi-arid regions, particularly, in the coastal regions where the ingress of sea water through estuaries, sea mists and rivers and through ground water causes large-scale salinization. Salinization causes land degradation and thereby reduces the productive capacity of agricultural lands, forestlands, and rangelands, and thus, it is considered as a desertification process (Mustafa, 2007). Salinization constrains the productive capacity of about one third of the worlds land and renders about half of the land in semi-arid and coastal regions barren and unsuitable for growing many crops (Kozlowski, 1997).

2.3 Impact of salts on productivity

Crops vary widely in their tolerance to salinity. Salt tolerance of a given crop may vary according to its stage of growth. In general, salts may affect plant growth directly by increasing the osmotic pressure of the soil solution, by accumulating a certain ion to a toxic level in plant tissues, and by causing nutritional imbalance (Ahmed, 1991). The plants that grow in saline soils have diverse ionic compositions and a range in concentration of dissolved salts. These concentrations fluctuate due to variation in water source, drainage, evapo-transpiration, and solute availability (Volkmar *et al*., 1998). Due to these varying conditions, plant growth depends on supply of inorganic nutrients, which vary in time and space. Extreme condition concerning nutrients results in deficiency or toxicity in plants depending on their salt tolerance (Maathius and Amtmann, 1999). The irrigation water contains calcium, magnesium, and sodium. As the water evaporates and transpires, calcium and magnesium are absorbed, leaving sodium dominant in the soil (Serrano *et al*., 1999). At low salt concentration, yields are mildly affected or not at all. As the concentration increases, the yield moves towards zero (Maggio *et al*., 2001). In the field, the salt level fluctuates seasonally and spatially, and variation will occur due to the circumstances influencing each particular plant. This variability makes research difficult. In order to judge the tolerance of plants to salinity, the growth or survival of the plant is measured because this is the culmination of many physiological mechanisms occurring within the plant. In low to moderate salinity conditions, salt exclusion is the strategy. Hence, the growth and yield are measured as indicators of salt stress. However, under higher salinity condition, ion toxicity may cause plant death and the survival limit may be measured (Niknam and McComb, 2000).

Sorghum is moderately tolerant to salinity (Maas *et al*., 1986) and is widely grown in semi-arid areas of East Africa on soils prone to salinity. Substantial genotypic differences exist among sorghum cultivars in response to salinity (Weimberg *et al*., 1982). These research workers aimed to quantify and evaluate the responses of total leaf area and physiological traits of photosynthesis to increasing NaCl concentrations in the rooting medium of two drought resistant varieties of Kenyan sorghum (Serena and Seredo). Varietal differences could be used as a source of variation for future plant breeding programs. These measurements of variables related to photosynthetic performance will compliment measurements of growth, water relations, and mineral ion distribution in tissues to salt stress (Netondo *et al.*, 2004).

Salts have two major effects on plant growth, namely osmotic and specific-ion effects (Bernstein and Hayward, 1958).

a. Osmotic impact

As the salt concentration (EC_e) increases, the osmotic potential (ψ_o) decreases according to the following relationship:

$$\psi_{o\,(bar)} = -0 \cdot 36\ EC_e$$

The uptake of water by plant roots is restricted by the decrease in osmotic potential (Eaton, 1941; Buckman and Brady, 1952; Richard, 1954). High soluble salt concentration brought in contact with the plant cell will result in the osmotic movement of water from the cell towards the more concentrated soil solution causing the cell to collapse (Buckman and Brady, 1952). Hegan (1973) found that at an osmotic potential ranging between - 3 to - 4 bars, the plant growth decreases, and the plant is killed at osmotic potential ranging between -5 to -6 bars. Donahue *et al.* (1983) stated that high salt concentration increases the potential factors that hold water in the soil and makes it more difficult for plant roots to extract the moisture. The low osmotic potential reduces the overall soil water potential and makes it difficult for the plant roots to extract sufficient water for its normal growth (Mustafa, 2007). Hanks and Saken (1977) reported that the main effect of salinity is the decrease of soil water availability for plant uptake. Plants growing in saline soils were relatively small in size, dark bluish-green in color and usually had thick coating of wax (Black, 1957). Richard (1954) stated that the primary harmful effect of excessive salinity is the increase of the concentration of soil solution, in consequence, the flow of water into the plant by osmosis is reduced or reversed and the plant is starved of water even though the soil is moist.

Salinity creates the specific problem of ion toxicity, because a high concentration of sodium is bad for the cell. High salt concentrations inhabit enzymes by impeding the balance of forces controlling the protein structure (Serrano *et al.*, 1999). The toxic effects of salt can occur at relatively low concentration, depending on the plant species, so the homeostasis of sodium is important for the tolerance of organisms to salt stress. The stress caused by ion concentrations allows the water gradient to decrease, making it more difficult for water and nutrients to move through the root membrane. In turn, the water uptake slows, and as the osmotic effect spreads from the root membrane to the internal membranes, the ion concentration inside the plant alters the solute balances. Once high concentrations of salt have reached the inside of the plant, tissue and organs development is altered. The salt causes a slower rate or shorter duration of expansion of cells and this compromises the size of the leaves (Volkmar *et al.*, 1998). The overall effect of salinity on plants is the eventual shrinkage of leaf size, which leads to death of the leaf, and finally the plant. Salinity may also cause reduced ATP and growth regulators in plants (Allen *et al.*, 1994).

b. Specific ion effect

Unlike most annual crops, trees and other woody perennials may be specifically sensitive to ions, such as chloride and sodium, which are taken up with soil water, move with the plant transpiration stream, and accumulate in the leaves. Crop varieties and rootstock differences in tolerances to chloride and sodium depend largely upon the rate of transport of these ions from the soil to the leaves.

Larson and Pierre (1953) indicated that the addition of either sodium or potassium depresses the uptake of calcium and magnesium. However, the addition of one may have little effect if calcium and magnesium have already been depressed by other. High pH levels common to high bicarbonate soils may cause reduced iron availability and consequent nutritional imbalance. High pH levels of sodic soils may accentuate deficiencies of many of the micronutrients (Mustafa, 2007). The presence of sodium chloride even caused some increase in potassium uptake. It is logical to expect that halophytes and salt-tolerant plants would have developed a mechanism for preferential uptake of potassium from mixtures rich in sodium (Epstein, 1972). Calcium was known to have an ameliorating effect on the growth of plants under saline conditions (Hyder and Greenway, 1965; Deo and Kanwar, 1969; Bernstein, 1970; and Epstein, 1972). Gale and Poljakoff-Mayber (1970) growing *Atriplex halmus* in media salinized to different levels with either NaCl or Na_2SO_4, found that Na_2SO_4 is much more damaging for the growth than NaCl. Sodium toxicity is often modified and reduced if calcium is present. Because of this interaction, a reasonable evaluation of the potential toxicity is given by the exchangeable sodium percentage (ESP) of the soil or the sodium adsorption ratio (SAR) of soil extracts or irrigation water (U.S.Salinity Laboratory Staff, 1954).

Page and Talibudeen (1982) indicated that the yield reduction of wheat, maize, peas, beans and sugar beet caused by higher potentials, were due to limitation of other cations rather than by toxic levels of potassium in the plant tissue. The soil dispersion and swelling increased, and the relative hydraulic conductivity of a Vertisol and an Aridisol decreased as their ESP increased and the total salt concentration in their solutions decreased (Hamid and Mustafa, 1975; Mustafa and Hamid, 1977; Mohamed and Mustafa, 2001). This indicates that the high ESP of sodic soils causes dispersion and swelling and thereby restricts the infiltration rate and causes poor aeration and indirectly reduces crop yield. Abrol *et al*. (1975) reported that increase of sodium caused poor physical soil properties, and raised soil pH, which caused nutritional imbalance in soil and consequent reduction of crop growth and yield. Malik *et al*. (1992) found that swelling and dispersion increased when SAR increased and/or salt concentration decreased. Boron, although an essential minor element, is phytotoxic if present in excess. Most boron toxicity problems arise from high concentrations in well water or spring located near geothermal areas or geological faults.

The response of plants to salt stress is based on the action of many defense proteins, which is not fully discovered. Osmotic stress and ion toxicity are the problems stemming from salt stress, and the resulting decrease in chemical activity causes cells to lose turgor. Cell growth depends on turgor to stretch the cell walls, and lack of turgor implies danger for cell survival. The plants defense against this salinity attack requires osmotic adjustment, and to a certain degree, this can be done through synthesis of intracellular solutes (Serrano *et al*., 1999).

2.4 Salt effects on soil

Salinity is the major and ever-present threat to the sustainability of irrigated agriculture in arid and semi-arid regions. Unless salinity is controlled, productivity decreases, land values drop, and, in severe cases, the land is completely abandoned. Exchangeable sodium has a marked influence on the chemical and physical properties of a sodic soil. As the proportion of the exchangeable sodium increases, the soil tends to exhibit poor tilth. The crusting tendency of such a soil is a serious hazard to seedling emergence, and often accounts for poor emergence and reduced crop yield. Malik (1983) studied the effect of mixed Na/Ca solution on swelling, dispersion and transient water flow in unsaturated montmorillonitic soils. Results showed that swelling and dispersion increased when Sodium Adsorption

Ratio (SAR) increased and/or electrolyte conductivity decreased. Also penetrability and unsaturated hydraulic conductivity decreased with the increase in SAR and/or decrease in electrolyte conductivity. Saleh and Letey (1990) studied the physical properties of a sodium- treated soil as affected by two polymers. Their investigation showed that increasing value of SAR lead to decreasing aggregate stability, increasing dry strength and decreasing flocculation of soil.

2.4.1 Soil salinity

The chemical and physical properties of air, soil and nutrients act, in most cases, in a multifactorial way, and in arid and semi-arid zones this phenomenon is most obvious in the development of the problem of soil salinity. Concurrently there is an increasing demand for new agricultural land in developing countries to feed their rapidly growing populations. Hence there is an urgent need to combat the effects of progressive loss of soil to agriculture through salinization.

Soil salinity may be assessed directly, by measuring total amount of soluble salts or indirectly, by measuring the electrical conductivity of the soil saturation extract at $25^{o}C$ (ECe). The soluble cations which give saline soil their characteristics include Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, and Cl^{-}, $SO_4{}^{2-}$, and $HCO_3{}^{-}$ are the predominant anions (Tanji, 1990). Of these, chlorides, sulphates, and bicarbonates of sodium, calcium, and magnesium are of frequent occurrence in saline soils and irrigation water. Saline soils have an electrical conductivity (EC) more than 4 dSm^{-1} in at least some part of the soil profile within 25 cm of the surface; exchangeable sodium percentage (ESP) < 15, pH ≤ 8.5. According to the presence and concentrations of cations and anions, electrical conductivity, and exchangeable sodium percentage, the US Salinity Laboratory Staff (1954) has classified salt-affected soils as: saline (EC > 4 dSm^{-1}, ESP < 15, pH ≤ 8.5), saline sodic (EC > 4dSm^{-1}, ESP > 15, pH ≤ 8.5), and non-saline sodic soils (EC < 4 dSm^{-1}, ESP > 15, pH ≥ 8.5).

2.5 Quality of irrigation water

2.5.1 Water resource

FAO/UNESCO (1967) determined the specific character of the irrigation water as a function of its origin. The water resources include the following:

a. Rain water

Rain water has the lowest salt content of all types of water used for irrigation. This water contains dissolved gases and dissolved salts originating from terrestrial and marine sources. Generally, the amount of ions in rain water (NH_4, Cl, and Na) varies widely and is dependent on the distance from the Sea and the areas of Aeolic deflation.

b. Surface water

The salt content of surface water is a function of the rocks prevalent at the water source, climate, nature of the soil over which the water flows and eventual pollutions by human activities.

c. Ground water

The salt content of ground water is dependent on the source of the water and the course over which it flows. Mineralization of ground water is in accordance with the law of dissolution, based on the contact between the water and the water bearing strata. Changes in the salt content of ground water in the recharge process result from reduction, base exchange, transpiration, evaporation and precipitation.

d. Sea water:

Sea water is a complex solution containing heterogeneous components, namely, ions, gases, organic matter, micro fauna, flora, etc. Among the chemical elements are: chloride ion (predominating with 55%), sodium (30%), sulfate (7%), magnesium (3.7%), and potassium (1.1%). Pickard (1964) noted that the range of surface water salinity values in the open Ocean is 33-37 g/l. higher values occur in regions with high evaporation such as the eastern Mediterranean (39 g/l) and the Red Sea (41 g/l). Sea water can be used for irrigation purposes only after being subjected to an industrial desalinization process.

2.5.2: Effects of irrigation water on soil

The main objective of irrigation is to supply sufficient water to sustain normal plant growth. Many irrigation water supplies contain a substantial amount of salt. Irrigation can contribute a substantial amount of salt to a field over the season. Salts accumulate in the root zone by two processes: The upward movement of a shallow saline-water table, upward rise of salt by capillarity and salt accumulation in the soil due to insufficient leaching. Leaching is the process of applying more water to the field than can be held by the soil in the crop root zone such that the excess water drains below the root system, carrying salt with it. The more water that is applied in excess of crop water requirement, the less salinity there is left in the root zone despite the fact that more salt has actually been added to the field. Increasing irrigation interval will prolong the reduction in plant turgor pressure and cause reduction in cell elongation and consequently in plant height (Heyn, 1940). Carter and Fanning (1964) studied the effect of application of cotton mulch on salt leaching. Water applied by periodic sprinkling of surface mulched soil resulted in salt removal higher than flooding and periodic sprinkling of bare soil. Abd Elrahim (1985) studied the effects of irrigation regimes and some soil amendment on salt redistribution, and production of forge sorghum. Results showed that irrigation every 7 days improved salt removal and dealkalinization of the soil and increased yield, leaf area index, plant height, and leaf nutrients up-take. Vassilar and Orcharova (1988) studied the effects of using sea water for irrigation of Alfalfa. Results showed that the most effective ratio proved to be 25% sea water to 75% fresh water. The trials also demonstrated that increased sodium content was neutralized by the presence of magnesium and calcium, and that no residual sodium carbonate resulted. Prunty *et al*. (1991) studied the effects of water quality on soil and Alfalfa water use, yield and nutrient concentration. His findings showed that in all soils and water, yield and water use decreased by 30 - 60 % by the end of the experiment. Mean nutrient concentration, except for sodium, which increased by 500 % during the experiment, remained within 10 % of the original values. Irrigation water with SAR of 20 and ionic concentration of 20 mmol/l increased sodium concentration to 15 times than that with distilled irrigation water.

2.5.3 Dealing with saline water

Water scarcity and the implications of population growth are threatening all arid regions. Most Arab countries (67%) are receiving rainfall less than 100 mm per year. About 15 to 17 million hectares of land per year were not utilized due to inadequate water resources (AOAD 2003).

An alternative approach for irrigation with saline water is to adopt the system commonly used by Iranian farmers, using water wells having EC ranging from < 5 to 11.8 dSm^{-1} (Aliazadeh *et al*.2004).

Other practices of blending fresh water and saline water to keep the salt load in the soil within acceptable limits were practiced in the Cholistan desert in Pakistan (Kahlown and Akram, 2004). Earlier (Ahi and Powers, 1938) grew halophytes with dilution of seawater. Daoud *et al*. (2004) grew eight halophytic species on five salinity levels of dilution of seawater, namely, tap water (control), 25, 50, 75 and 100% seawater; the result showed an increase in dry weight yield in low and moderate salinity levels.
Salinity of seawater exceeds the limit tolerated by conventional crop yields. An alternative method is the domestication of naturally occurring halophytes having different levels of salt tolerance (Glenn *et al*. 1993).

Use of sea water in agriculture has led to more emphasis on fresh water conservation as found in experiments conducted in United Arab Emirates (Riley *et al*., 1994). Magboul (2004) has grown salicornia species using sea water of the Arabian Gulf.

Concentrating on larger scale methods of dealing with salt stress, plants have several mechanisms to adjust to a saline environment. Abundant of information states that roots play a crucial role for short-term adaptation to salt tolerance. The concentrated salts surround the root membrane, and hence morphology of the roots affects the amount of salt taken into the plant (Maggio *et al*., 2001). Some features of root are advantageous because they help the root to take in water. Because salinity is first perceived in the root, the root sends the signal hormone abscisic acid, which directly or indirectly down regulates the leaf expansion rate (Rausch *et al*., 1996). Salt exclusion from the root is likely to be part of the salt tolerance found in plants. However, when salt ions make it into the plant, they accumulate in the leaf. As stated above, it is beneficial to the cells of the leaves to compartmentalize the salt ions into the vacuoles. Leaf cell growth is sensitive to salt, because the energy used for compartmentalization takes energy away from cell growth (Volkmar *et al*., 1998). The root signal tells the shoot to stop growing to conserve energy as well. Growth could be considered as a means of regulating the concentration of salt, although high concentrations of salt induce inhibition of growth when the plant needs to continue growth to dilute salt concentrations and find space for vacuoles. All of these broad reactions to salt stress could be target systems to regulate tolerance by the plants: the structural components of the roots, ion transporters, or cell wall and membrane component (Winicov and Bastola, 1997). These mechanisms constitute the only way that plants can adapt to saline conditions themselves, but there having been suggestions of external maneuvers to counteract the salinity.

Many other studies have shown that salt stress can also be alleviated by an increased supply of calcium to the growth medium. Depending on the concentration ratio, sodium and calcium can replace each other from the plasma membrane, and calcium might reduce salt toxicity (Rausch *et al*., 1996). If none of these mechanisms are available to the plant, eventually the leaf death rate will overcome the leaf growth rate and plant death will occur.

2.5.4 Drainage

Drainage is important to limit excessive amount of water in the rooting zone that hinders the removable of excess salts (Richards *et al*.1969; Fireman 1957). Irrigation without drainage can cause unduly rise of water table (Dutt and Tanji 1962; Doneen *et al*. 1967; Al-Jaloud and Husain 2004).

2.6 Management options for saline irrigation water

A detailed treatment of management of salt-affected soils was presented by Mustafa (2007). Most of the recommended steps may prove useful in managing irrigation with saline water. Awad, 1984; ANCID, 2001 reported that if you have to use saline water for irrigation you need to understand how salinity affects a crop.

2.6.1 Mulching

As saline water evaporates from the soil it leaves behind salts. A good mulch under the crop helps reduce surface evaporation, maintains moisture near the soil surface and lessens the build up of soil salinity.

2.6.2 Leaching

The main method of reducing the effect of saline water is to apply extra water to leach salts below the root zone. The extra irrigation water needed to leach salts is termed the leaching fraction, and this can be calculated for various crops and soil types.

2.6.3 Salt index of fertilizers

All fertilizers have a salt index which indicates what the fertilizer contributes to soil salinity. If your irrigation water or soils are saline, changing to fertilizers with similar nutrients but with a lower salt index may help.

2.6.4 Desalinization

Desalinization for saline waters is technically possible, but its use is limited by cost and the problem of disposing of the residual saline concentrate. Normal agricultural uses would not warrant the cost and maintenance of desalinization.

Chapter three

Materials and Methods

3.1 Study Area

3.1.1 Location

The Red Sea is a narrow elongated body of water running NNW-SSE between the land masses of Africa and Arabia (Moroces, 1970). It extends South East- North West between 12ºN, 43ºE and 30ºN, 32ºE (PERSGA, 2001). The Red sea is approximately 2000 km long and the Sudanese coastline includes approximately 50 km of this strip. The coastal fringe of the Sudan occupies a narrow strip (20 - 40 km) lying between lat.18º23`N and long. 33º39`E. (Ali and Mohamed, 1991).

3.1.2 Geomorphology

The coasts of the Red Sea extend through a vast area of desert and semi-desert land called Tahama (PERSGA, 2003), typically bounded by narrow (1-50 km) coast strip, backed by high hills, which rise to 3000 m in some regions (Cox 1931; Guilcher 1955; Allan and Morelli 1970; and Dubertret 1970).

3.1.3 Climate

In the northern Red Sea the prevailing wind direction is NE during winter and southerly winds during summer. In the Southern Red Sea (south of 20 N) the prevailing wind direction in summer is northerly whilst in winter is SSE (UNEP, 1985).

Annual mean temperature fluctuates around 30ºC over the central and the northern parts. However, temperature as high as 46ºC may be experienced. Generally, January is the coldest month (23.7ºC). June is usually the hottest month over the southern half of the region (32.2ºC), while July is the hottest month over the northern half (35ºC). The mean annual rainfall is 36.1 mm at Halaib in the north, 89.3 mm at Port Sudan, and 163.8 mm at Suakin. The mean annual rainfall throughout the Red sea is very low and subject to great variation from year to year. Generally, over 70% of the rainfall occurs during winter (October - January).

Relative humidity is generally high and exhibits spatial variation along the coast and temporal variation among seasons. The highest values occur during the winter rainy season (October - January) ranging between 70% - 79% in Port Sudan and 64% - 69% in Toker. However, relatively lower means are observed for the rest of the year (February - September). The lowest means (38 - 65%) are encountered during summer dry months, June and July (Sudan Meteorological Services Department, 1951-1980).

3.1.4 Water Resources

Seasonal streams (khors) are the main sources of water in the State, namely Khor Arbaat, Khor Baraka, Khor Arab and Wadi Eldaib. These streams usually flow either in western or eastern direction towards the Sea. Most of these Khors, specially which drain in the Red Sea are characterized by high speed due to steep slopes resulting in low infiltration rates and low recharge of under ground water (Ministry of Agriculture and Animal Resources and Irrigation, 2000). Khor Arbaat, Khor Arous north of Port Sudan and Khor Gowb south of Port Sudan are the most prominent khors at the coastal plain (Mohamed, 1999).

3.1.5 Soils

The coastal plain is a flat strip dissected by a number of khors, which drain into the Sea (Sulaiman and Musa, 1989).

In general, the soils are sandy mixed with alluvial sediment, which is carried by rain water from the nearby Red Sea Hills and Forms loamy sand to sandy loam soils (Ali and Mohamed, 1991). The soils are coarse-textured, Porous and calcareous. Soil surface is exposed to sheet wash by winter rains and sand dune accumulation in summer (Gadalla, 1994).

3.2 Materials

A loamy sand soil was collected from West Omdurman. Sea water was brought by a tanker from the Red Sea at Port Sudan.

3.3 Methods

3.3.1 Soil and water analysis

The soil was analyzed before irrigation. pH of saturated soil-paste was measured by a pH meter. The electrical conductivity of the saturated soil paste extract (EC_e) and seawater (EC) were measured using an EC meter (Richards et al. 1969). Particle size distribution was determined by the hydrometer method (Black *et al*., 1965).

The sum of calcium and magnesium was determined by titration by the versenate method according to Chen and Bray (1951) and Diehl et al. (1950). Na^+ and K^+ were determined by flame photometer, and CO_3, HCO_3, and Cl were determined according to Richards *et al*. (1969). SO_4 was calculated by difference between the sum of measured anions and cations. SAR was calculated by the following equation:

$$\mathrm{SAR} = \frac{[Na^+]}{\sqrt{\frac{[Ca + Mg]}{2}}}$$

Where: ion concentration was expressed in $mmole^+/l$.

The electrical conductivity of mixed Red Sea water with freshwater was measured both by EC meter and according to formula given by Richards (1954) as follows:

$$EC_M = \frac{EC_S V_S + EC_F V_F}{V_S + V_F}$$

Where: EC_M = EC of mixed Seawater with freshwater.

V_S and EC_S = Volume and Electrical conductivity of Seawater.

V_F and EC_F = Volume and Electrical conductivity of Fresh water.

The properties of the soil used are reported in Table 3.1.

Table 3.1: The soil physical and chemical characteristics:

Soil type	EC_e	SAR	pH	O.M*	Sand%	Silt%	Clay%
Loamy Sand soil	0.8	6.0	8.3	0.3	81.4	4.1	14.5

*O.M = Organic Matter.

3.4 Irrigation Water

Red Sea water was mixed with freshwater (EC 0.4 dSm^{-1}) to attain different levels of salinity for irrigation of the selected types of plants at germination in the laboratory and at different stages of vegetative growth in pots.

The chemical properties of the Seawater are presented in Table 3.2.

Table 3.2: Main chemical properties of the Red Sea water.

Cations (me/L)					Anions (me/L)				EC dSm^{-1}
Na	Ca	Mg	K	T.D.S	Cl	CO_3	HCO_3	SO_4	
653	28	121	138.1	940.1	835	-	14.7	72.4	57

3.5 The pot experiment

The experiment was undertaken to simulate the growth of millet and sorghum in the loamy sand soils in the red sea coast using mixed Red Sea - Rain water. Seven kilograms of the soil were placed in cylindrical glazed iron pots with bottom drainage, 17 cm in height and 20 cm internal diameter. The soil was packed, by gentle tapping of the pot to attain a height of 13 cm within the pot. The top 4 cm of pots were left for irrigation water.

In the first season, the experimental treatments consisted of five water salinity levels, namely, 0.4 tap water, 3.1, 5.5, 9.3, and 16.6 dS/m, three irrigation frequencies 2, 4, and 7days, and presence or absence of organic mulch, one soil and one crop (millet) were used. Each treatment was replicate thrice. Ninety pots (5×3×2×3) were used in this experiment. The experiment was conducted in the Nursery of the horticultural orchard of the Faculty of Agriculture, University of Khartoum.

In the second season, the experimental treatments consisted of four water salinity levels: 0.4 tap water, 3.1, 5.5, and 9.3 dS/m, three sorghum varieties, four replicates. The irrigation interval was two days. One type of soil was used. Forty eight pots (4×3×4) were used in this experiment. The experiment was conducted in the glass house Faculty of Agriculture, University of Khartoum. In both seasons the pots were arranged in completely randomized design.

Twenty five seeds of the crops were sown in each pot and each was irrigated during the four weeks on germination and seedling stage by freshwater having EC = 0.4 dSm^{-1} . Plants of each crop were then thinned to similar stand on each pot one week after germination. Irrigation with mixed water of different salinity level was initiated after four weeks.

The experiment was carried out for two seasons: winter seasons starting 20 December 2006 to 20 March 2007 and a summer season starting first June to 11 September 2007, monthly maximum and minimum temperatures, relative humidity, and total rainfall were recorded during the two seasons. The long-term data for evaporation in Shambat was used for calculating the quantity of irrigation water to be added for each salinity level. After each irrigated the quantity and EC of the leachate were measured.

3.5.1 Estimation of irrigation water requirement (WRi)

The crop reference evapotranspiration (ETr) was calculated using the following Jensen-Haise equation (Jensen, 1983). It was the result of a review of about 3000 measurements of ET that were made in the Western United States for about 35 year period.

The Jensen-Haise method is as follows:

$$E_{tr} = C_T (T - T_x) R_s$$

Where E_{tr} (Evapotranspiration) has the same units as R_s (Radiation Solar) and is compatible with alfalfa based crop coefficients.

$$C_T = \frac{1}{C_1 + 7.3\ C_H}$$

$$C_H = \frac{50\ mb}{e_2 - e_1}$$

where e_2 is the saturation vapor pressure of water in mb at mean monthly maximum air temperature of the warmest month in the year (long term climatic data), and e_1 is the saturation vapor pressure of water in mb at the mean monthly minimum air temperature of the warmest month in the year.

$$C_1 = \frac{38 - 2\ E}{305}$$

Where: E = the site elevation in m.

$$T_x = -2.5 - 0.14(e_2 - e_1) - \frac{E}{550}$$

Solar radiation may be measured or estimated.

The mean monthly R_s was estimated by the following relationship:

$$R_s = R_a\left(0.25 + 0.5\frac{n}{N}\right)$$

Where R_a is the mean monthly extraterrestrial radiation obtained from Table 10 in Doorenbos and Pruitt (1977).

n is the sunshine hours .

N is the daily duration of maximum possible sunshine hours obtained from Table 11 in Doorenbos and Pruitt (1977).

Both R_a and N obtained for each month, using Shambat latitude.

The crop evapotranspiration (ETc) is estimated from reference evapotranspiration (ETr) and crop factor (Kc) by the following equation:

$$ETc = Kc\ ETr.$$

The depth of the irrigation water requirement WRi was calculated by using the following relationship:

$$WRi = \frac{ETc}{1 - LF}$$

Where LF is the leaching fraction, which was calculated by the following equation:

$$LF = \frac{ECi}{5\ ECi - EC_e} \cdot \frac{1}{LE}$$

Where: ECi is the EC of the irrigation water, EC_e is the EC_e of the root zone soil that reduces the crop yield by 10% and for millet was assumed to be equal to 6 dS/m. LE is the leaching efficiency assumed to be 90%. The ECi values were 0.4, 3.1, 5.5, 9.3, and 16.6 dS/m, for Seawater. Water ratios of 0:1, 1:20, 1:10, 1:5, and 1:2.5, respectively. The quantity of water requirement for irrigation was proportion to the irrigation interval (Appendix 1, 2, 3, 4).

3.6 Standard Germination Test

The germination test was carried out to determine the effect of salinity on the standard germination and its relationship with seed vigor. Twenty-five seeds, replicated three times were used for the two seasons, and were arranged in completely randomized design. In the two seasons, seeds were planted in Petri-dishes with two filter papers at the bottom of the dish; a third paper was placed over the seeds. The three papers were moistened with tap water and salinity solutions. The seeds were kept in the dark in the germination room at 20 ±1º C for ten days according to ISTA result. Daily counts of normal seedling were recorded. At the end of the incubation period, the number of normal seedling was recorded.

3.6.1 Germination Percent

Number of germinated seeds was counted for the three types of plants every 24 hours, and the germination percent was computed by the following formula:

$$\text{Germination \%} = \frac{\text{No. of seeds germinated} \times 100}{\text{Total No. of seeds in Petri dishes}}$$

3.7 Plant Height

Five randomly selected plants from each pot were measured every two weeks to obtain height of plants above soil level.

Mean height was measured by the following formula:

$$\text{Mean height (cm)} = \frac{\text{Total of height of 5 plants (cm)}}{\mathbf{5}}$$

3.8 Source of Seeds

Millet (Pennisetum americanum) seeds in the first season were provided from Port Sudan in Red Sea State, and local name Tokarawy.

In the second season, the following three Sorghum (Sorghum bicolor) varieties were used:

- Aklomoy its Local name, provided from Port Sudan.
- Wad Ahmed, provided from the department of Agronomy Faculty of Agriculture, University of Khartoum.
- R5, provided from the department of Agronomy Faculty of Agriculture, University of Khartoum.

3.9 Statistical Analysis

SAS (Statistical Analysis System) was used for comparing the effects of salinities of mixed waters on seed germination using CRD statistical design and the effects of waters on plants growth in soils were analyzed using the Factorial Complete Randomized design.

Chapter Four

Results

4.1 Germination Test

4.1.1 Millet

The level of salinity of mixed sea-tap water significantly ($P<0.001$) affected the germination percentage of millet at all periods (Table 4.1).

Fig. 4.1 Shows that the germination percentage decreased significantly ($P< 0.001$) with increase in EC of the mixed water. It was evident that after 2 days the seeds in mixed waters at 9.3 and 16.6 dS/m did not germinate. The germination in the two waters occurred after 3 and 4 days, respectively. After 8 days the germination% decreased linearly according to the following relationship:

$$\text{Germination } \% = -3.07\ EC + 92.3 \qquad r^2 = 0.9385$$

Fig. 4.2 Shows that in tap water (EC = 0.4 dS/m), the germination percentage increased linearly with increase of period. In the highest salinity water the trend line was qualitatively similar to that of tap water.

Table 4.1 The effect of the EC of mixed sea–tap water and period on germination percentage of millet at room temperature.

EC (dS/m)	Period (days)						
	2	3	4	5	6	7	8
0.4	33.2	48	52	58	74.7	81.2	92
3.1	29.2	53.2	58.7	80	88	88	88
5.5	18.8	29.2	41.2	48	60	72	72
9.3	0	21.2	34.8	50.8	57.2	57.2	57.2
16.6	0	0	14.7	26.7	40	45.2	45.2
Mean Germination%	16.2	30.3	40.3	53	64	69	71
LSD	1.63	2.105	2.047	1.409	1.936	2.153	2.1
Prob	0.0038	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

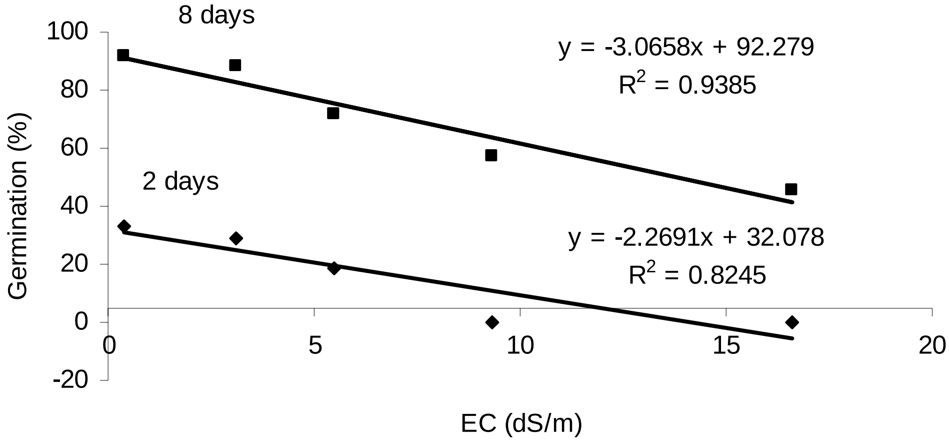

Fig.4.1 The effect of EC of mixed sea-tap water at two periods on germination of millet

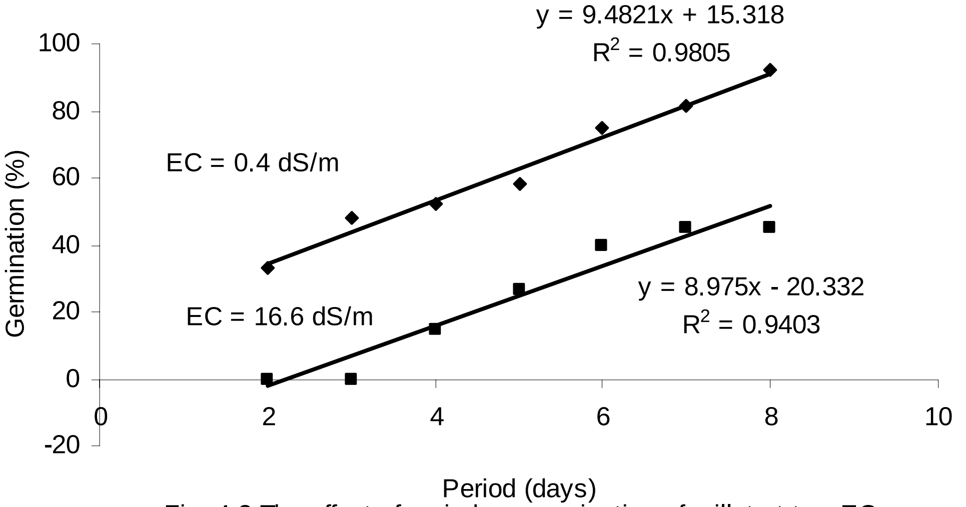

Fig. 4.2 The effect of period on germination of millet at two EC values of mixed sea-tap water

4.1.2 **Sorghum bicolor (Aklomoy)**

The level of salinity of mixed sea-tap water significantly ($P<0.001$) affected the germination percentage of sorghum (Aklomoy) at all periods (Table 4.2).

Fig. 4.3 shows that the germination percentage decreased significantly ($P< 0.001$) with increase in EC of the mixed water. It was evident that after 2 days the seeds in mixed waters at 5.5 and 9.3 dS/m did not germinate. This germination occurred after 3 and 4 days, respectively. After 8 days the germination% decreased linearly according to the following relationship:

Germination % = - 6.2 EC + 104.8 $r^2 = 0.9095$

Fig. 4.4 Shows that in tap water (EC = 0.4 dS/m), the germination percentage increased linearly with increase of period. Even in the highest salinity water the germination percentage increased linearly with increase of period. However the rate of increase of germination percentage was lower than that in tap water.

Table 4.2 The effect of the EC of mixed sea–tap water and period on germination percentage of sorghum (Aklomoy) at room temperature.

EC (dS/m)	Period (days)						
	2	3	4	5	6	7	8
0.4	33.2	54.7	68	81.2	93.2	97.2	97.2
3.1	32	53.2	76	80	90.7	93.2	96
5.5	0	20	42.7	53.2	61.2	64	65.2
9.3	0	0	24	38.7	42.7	45.2	46.7
Mean Germination%	16.3	32	52.7	63.3	72	75	76.3
LSD	2.448	3.194	2.549	1.631	2.174	2.663	2.663
Prob	0.725	0.0009	0.0001	0.0001	0.0001	0.0001	0.0001

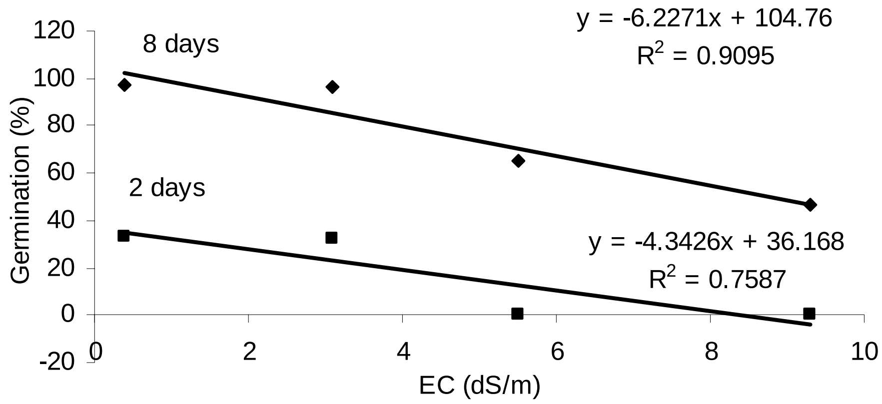

Fig. 4.3 The effect of EC of mixed sea-tap water at two periods of germination of sorghum (Aklomoy)

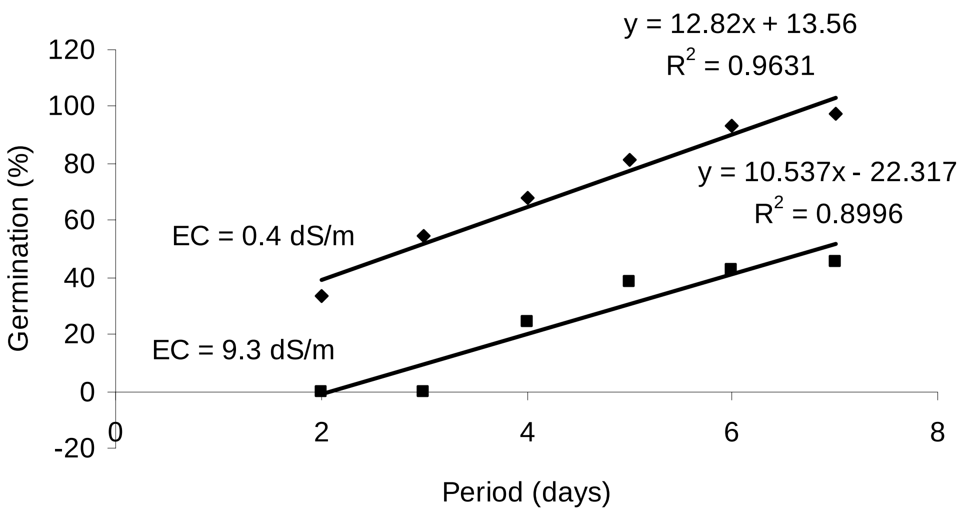

Fig. 4.4 The effect of period on germination of sorghum (Aklomoy) at two EC valuses of mixed sea-tap water

4.1.3 Sorghum bicolor (Wad Ahmed)

The level of salinity of mixed sea-tap water significantly ($P<0.001$) affected the germination percentage of Wad Ahmed at all periods except after 2 days it's not significantly ($P<0.001$) affected (Table 4.3).

Fig. 4.5 shows that the germination percentage decreased significantly ($P< 0.001$) with increase in EC of the mixed water. It is evident that after 2 days the seeds in mixed waters at 9.3 dS/m did not germinate. This germination occurred after 3 days. After 8 days the germination% decreased linearly according to the following relationship:

Germination % = - 2.9 EC + 96.4 $r^2 = 0.9181$

Fig. 4.6 Shows that in tap water (EC = 0.4 dS/m), the germination percentage increased linearly with increase of period. In the highest salinity water the germination percentage increased linearly with increase of period.

Table 4.3 The effect of the EC of mixed sea–tap water and period on germination percentage of sorghum (Wad Ahmed) at room temperature.

EC (dS/m)	Period (days)						
	2	3	4	5	6	7	8
0.4	29.2	44	64	85.2	94.7	94.7	94.7
3.1	20	37.2	48	69.2	86.7	88	90.7
5.5	17.2	33.2	48	73.2	76	76	76
9.3	0	13.2	36	54.7	69.2	70.7	70.7
Mean Germination%	16.6	32	49	70.6	81.7	82.4	83
LSD	3.586	1.883	1.883	2.549	3.122	2.927	2.824
Prob	0.1800	0.0001	0.0002	0.0009	0.0070	0.0055	0.0033

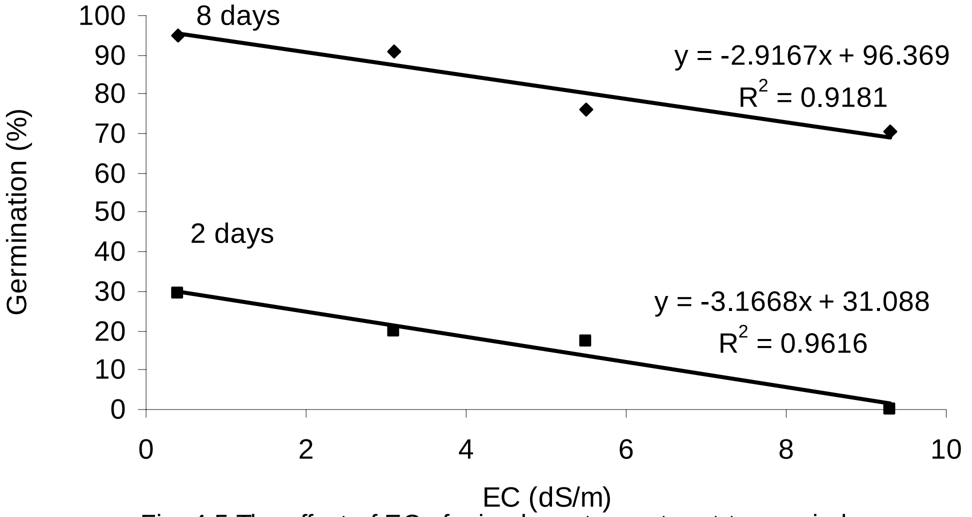

Fig. 4.5 The effect of EC of mixed sea-tap water at two periods on germination of sorghum (Wad Ahmed)

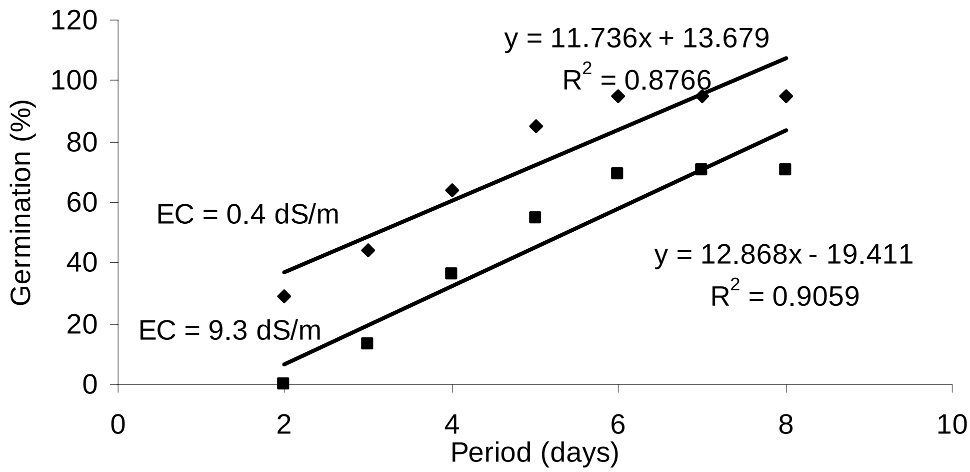

Fig.4.6 The effect of period on germination of sorghum (Wad Ahmed) at two EC values of mixed sea-tap water

4.1.4 Sorghum bicolor (R5)

The level of salinity of mixed sea-tap water significantly ($P<0.001$) affected the germination percentage of R5 at all periods (Table 4.4).

Fig. 4.7 shows that the germination percentage decreased significantly ($P< 0.001$) with increase in EC of the mixed water. It is evident that after 2 days the seeds in mixed waters at 9.3 dS/m did not germinate. This germination occurred after 3 days. After 8 days the germination% decreased linearly according to the following relationship:

$$\text{Germination \%} = -3.6\ EC + 96.2 \qquad r^2 = 0.8589$$

Fig. 4.8 Shows that in tap water (EC = 0.4 dS/m) and the highest salinity water, the germination percentage increased linearly with increase of period. The trendline was similar to the germination percentage.

Table 4.4 The effect of the EC of mixed sea–tap water and period on germination percentage of sorghum (R5) at room temperature.

EC (dS/m)	Period (days)						
	2	3	4	5	6	7	8
0.4	20	45.2	53.2	70.7	85.2	89.2	89.2
3.1	13.2	32	45.2	58.7	78.7	86.7	90.7
5.5	13.2	26.7	44	61.2	80	80	80
9.3	0	13.2	29.2	52	58.7	58.7	58.7
Mean Germination%	11.6	29.3	43	60.7	75.7	78.7	80
LSD	2.824	2.491	2.105	2.977	3.122	2.663	2.977
Prob	0.0033	0.0006	0.0012	0.0397	0.0055	0.0006	0.0009

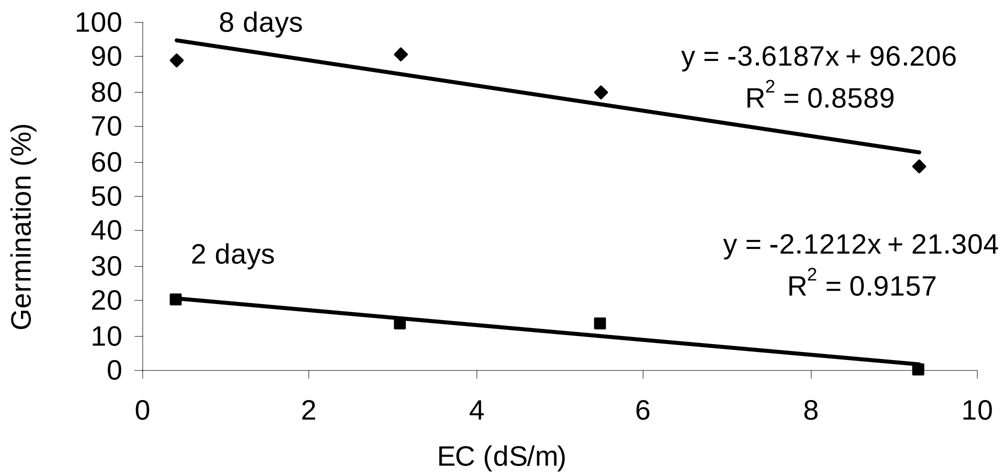

Fig.4.7 The effect of EC of mixed sea-tap water at two periods on germination of sorghum (R5)

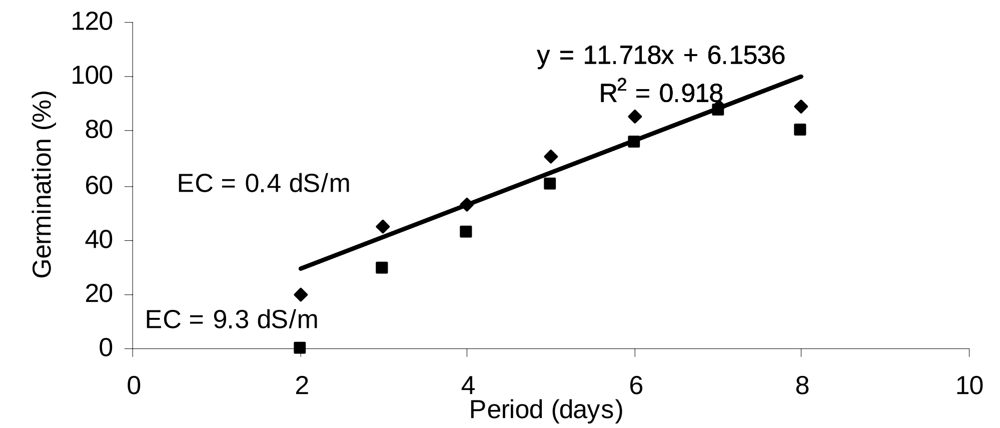

Fig.4.8 The effect of period on germination of sorghum (R5) at two EC values of mixed sea-tap water

4.2 Effects of treatments on plant height

4.2.1 First season results

Tables 4.5, 4.6 and 4.7 show the effect of period and EC of tap and mixed sea-tap waters on millet plant height grown on non-mulched and mulched soils and irrigated every 2, 4 and 7 days, respectively.

In general, the height of millet plants irrigated with waters of different EC values applied at different irrigation intervals and grown on non-mulched or mulched soil significantly increased linearly with increase of time (Fig 4.9, 4.10, 4.11). However, the growth period varied with EC of the mixed irrigation water.

(a) Two-day irrigation interval

The millet plants growing in non-mulched soil irrigated with tap water and mixed water having an EC value equal to 3.1 reached a height of 44.3 and 46.0 cm, respectively by the end of the 7th week. Millet plants irrigated with mixed waters having EC values of 5.5, 9.3 and 16.6 dS m^{-1} reached heights of 21.7, 17 and 14.7 cm, respectively, and EC values of 5.5, 9.3 and 16.6 dS m^{-1} reached these heights in the 5th, 4th and 3rd week, respectively and they died after that.

The impact of salinity on plant height was not significant in the first and second weeks. In the 3rd to 5th week, plant height showed significant quadratic decrease with increase of EC of the irrigation waters. The data of the third week yielded the following relationship:

$$H = 0.0665\ EC^2 - 1.7494\ EC + 25.463 \qquad (r^2 = 0.8302)$$

It is clear that mixed water with EC equal to 3.1 gave slightly but not significantly higher plants than tap water.

The trends of the effect of periods and EC of irrigation waters on plant height on mulched soil were similar to that of non-mulched soil. In general, mulching reduced plant height of plant irrigated with EC values ≤ 3.1 dS/m, and it increased it when the plants were irrigated with water having EC > 3.1 (Table 4.5). The data show that the impact of mulching was reduced with increase in the EC of the mixed water.

The mulched soil yielded the following relationship between H and EC for the third week:

$$H = 0.0091\ EC^2 + 0.4477\ EC + 20.57 \qquad (r^2 = 0.6672)$$

(b) Four- and seven-day irrigation intervals

In general, plant height increased with increase of irrigation interval (Table 4.6, 4.7). After seven weeks, the plant height of millet grown on non-mulched soil irrigated with tap water every 2, 4 and 7 days were about 44, 46 and 53 cm, respectively. After 5 weeks, the height of plants irrigated with mixed water having an EC equal to 5.5 dS/m was about 22, 24 and 33 cm for the same irrigation intervals in sequence. After the fifth week the plants irrigated every 2 and 4 days died, but those irrigated every 7 days continued growth in the sixth week reaching a height of about 42 before their death. Plants irrigated with mixed water having an EC equal to 9.3 dS/m every 2, 4 and 7 days continued growth to the fourth week reaching a height of 17, 18 and 26, respectively before collapsing. Plants irrigated with mixed water having an EC equal to 16.6 dS/m every 2, 4 and 7 days continued growth to the third week reaching a height of about 15, 15 and 18, respectively before collapsing.

In general, plant height decreased with increase of EC of the irrigation water on non-mulched and mulched soils. Initially the decrease was steeper for the 2 - and 4

- day irrigation intervals and gradual for the 7 - day interval (Table 4.5, 4.6, 4.7). The following quadratic relationships of height (H) versus EC of water were obtained for the various intervals:

2-day irrigation interval

$H = 0.0665\ EC^2 – 1.7494\ EC + 25.463$ $(r^2 = 0.8302)$

4-day irrigation interval

$H = 0.0526\ EC^2 – 1.5898\ EC + 26,531$ $(r^2 = 0.8869)$

7-day irrigation interval

$H = 0.0328\ EC^2 – 1.0984\ EC + 26.933$ $(r^2 = 0.8936)$

Using this equation the height of millet irrigated every 2, 4 or 7 days with mixed water of EC equal to 3 dS/m was about 21, 22 and 24, respectively. For mixed water of EC equal to 5 dS/m, the height of millet for the three irrigation interval in sequence was 18, 20 and 22, respectively. It was evident that plant height increased with increase of the irrigation interval (Quantity of irrigation is proportion to the irrigation interval).

Table 4.5 Effect of period and EC of tap and mixed sea-tap waters on millet plant height irrigated at an interval of two days on non-mulched and mulched soils.

EC (dS/m)	Period (week)						
	1	2	3	4	5	6	7
Not Mulched							
0.4	12.3	15.3	24.0	32.3	38.6	42.3	44.3
3.1	12.0	17.0	23.3	33.3	41.0	44.7	46.0
5.5	12.0	14.0	15.3	20/7	21.7	-	-
9.3	12.3	14.0	15.7	17.0	-	-	-
16.6	12.0	13.0	14.7	-	-	-	-
Mulched							
0.4	11.0	13.7	19.3	24.7	29.7	32.7	40.0
3.1	11.0	15.3	20.7	26.3	31.3	34.7	42.0
5.5	13.0	15.7	19.3	24.7	26.0	-	-
9.3	13.0	14.0	15.6	17.5	-	-	-
16.6	13.0	13.7	16.0	-	-	-	-
LSD	1.34	1.12	2.016	2.355	3.311	4.013	2.690
Prob	0.707	0.087	0.0001	0.0001	0.0001	0.0031	0.029

Table 4.6 Effect of period and EC of tap and mixed sea-tap waters on millet plant height irrigated at an interval of four days on non-mulched and mulched soils.

EC (dS/m)	Period (week)						
	1	2	3	4	5	6	7
Not Mulched Soil							
0.4	12.5	19.5	25.5	35.3	40.0	43.5	46.0
3.1	12.5	16.3	24.0	37.0	42.7	45.0	48.0
5.5	12.0	13.0	17.0	22.5	24.0	-	-
9.3	13.0	17.0	17.3	18	-	-	-
16.6	12.0	13.0	14.5	-	-	-	-
Mulched Soil							
0.4	12.0	13.5	20.0	27.3	35.0	41.7	45.0
3.1	11.0	15.7	21.3	30.0	32.7	40.3	46.5
5.5	12.5	16/0	20.7	25.0	28.5	-	-
9.3	13.0	13.5	15.5	18.7	-	-	-
16.6	12.5	12.7	15.0	-	-	-	-
LSD	1.36	1.23	1.527	2.231	3.311	3.013	2.350
Prob	0.657	0.035	0.0001	0.0033	0.0001	0.0024	0.018

Table 4.7 Effect of period and EC of tap and mixed sea-tap waters on millet plant height irrigated at an interval of seven days on non-mulched and mulched soils.

EC (dS/m)	Period (week)						
	1	2	3	4	5	6	7
Not Mulched Soil							
0.4	12.0	19.3	26.0	37.3	41.3	45.0	52.7
3.1	12.5	17.7	25.5	39.0	43.7	48.5	55.3
5.5	12.7	14.0	20.3	24.0	32.5	42.3	-
9.3	13.3	17.5	20.0	25.5	-	-	-
16.6	13.0	13.5	17.7	-	-	-	-
Mulched Soil							
0.4	13.7	14.0	24.0	27.3	37.0	42.5	54.0
3.1	12.5	16.3	22.7	29.5	36.3	46.0	53.5
5.5	12.0	17.7	21.3	26.0	33.7	40.5	-
9.3	13.3	14.3	18.0	22.7	-	-	-
16.6	13.0	14.0	17.5	-	-	-	-
LSD	1.362	1.235	1.534	3.522	3.211	4.542	3.541
Prob	0.587	0.0353	0.0001	0.0001	0.0001	0.0021	0.035

Table 4.8 Effect of period expressed in weeks (W) at designated EC values of tap or mixed sea-tap water on millet plant height (H) irrigated every 2 days as shown by the following regression trendline (H = b W + a)

EC (dS:m)	b	a	r^2
Not Mulched Soil			
0.4	5.88	6.36	0.9673
3.1	6.25	6.03	0.9664
5.5	2.61	8.91	0.9418
9.3	1.58	10.8	0.9962
16.6	1.35	10.53	0.9781
Mulched Soil			
0.4	4.84	5.10	0.9913
3.1	5.09	5.56	0.9956
5.5	3.50	9.24	0.9743
9.3	1.51	11.25	0.9822
16.6	1.50	11.23	0.9134

Table 4.9 Effect of period expressed in weeks (W) at designated EC values of tap or mixed sea-tap water on plant height (H) as shown by the following regression trendline (H = b W + a)

EC (dS:m)	b	a	r^2
Not Mulched Soil			
0.4	5.82	8.47	0.9668
3.1	6.52	6.13	0.9489
5.5	3.35	7.65	0.9527
9.3	1.53	12.50	0.7666
16.6	1.25	10.67	0.9868
Mulched Soil			
0.4	6.09	3.44	0.9819
3.1	5.97	4.34	0/9928
5.5	4.10	8.24	0.9974
9.3	1.91	10.40	0.9090
16.6	1.25	10/90	0.8096

Table 4.10 Effect of period expressed in weeks (W) at designated EC values of tap or mixed sea-tap water on plant height (H) of millet irrigated every 7 days as shown by the following regression trendline (H = b W + a)

EC (dS:m)	b	a	r^2
Not Mulched Soil			
0.4	6.74	6.40	0.9821
3.1	7.44	4.86	0.9794
5.5	5.92	3.58	0.9465
9.3	3.91	9.30	0.9804
16.6	2.35	10.03	0.8288
Mulched Soil			
0.4	6.82	3.09	0.9674
3.1	7.00	2.97	0.9879
5.5	5.58	5.68	0.9849
9.3	3.19	9.10	0.9345
16.6	2.25	10.33	0.9067

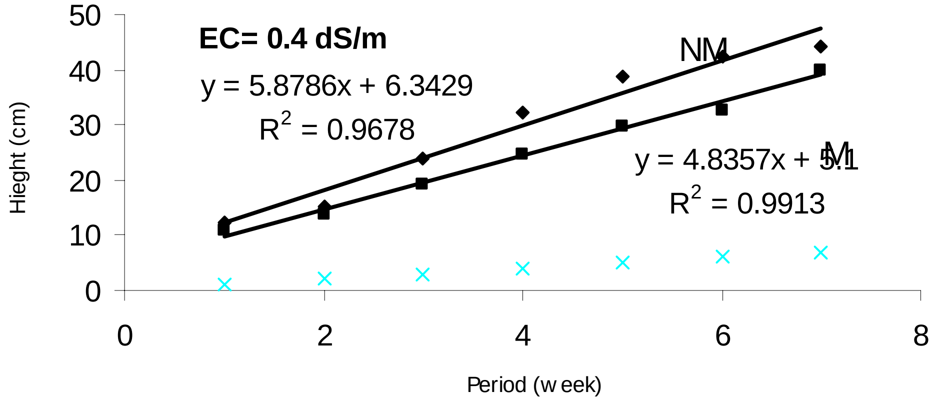

Fig. 4. 9. Effect of period on plant height of millet grown in mulched (M) and notmulched (NM)soil and irrigated every two days with tap water.

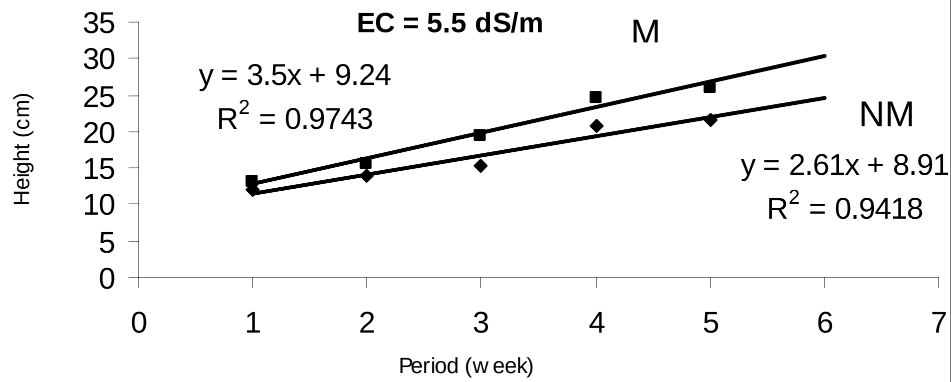

Fig. 4.10. Effect of period on plant height of millet grown in mulched (M) and not mulched (NM) soils and irrigated every two days with mixed sea-tap waters.

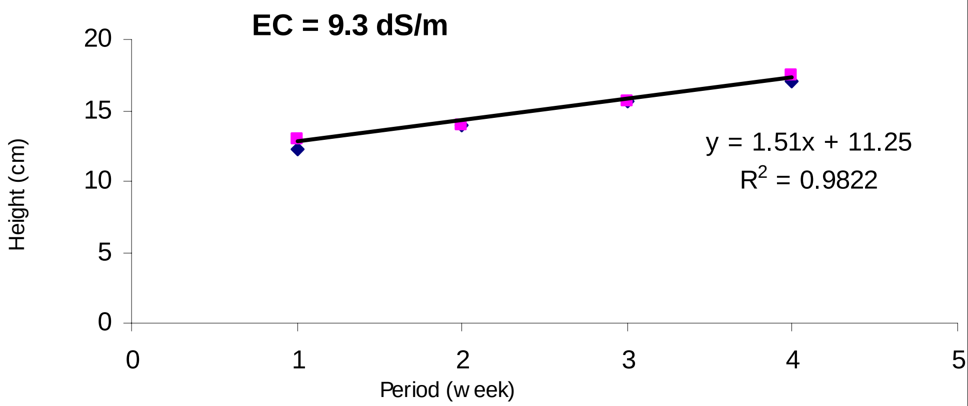

Fig. 4.11. Effect of period on plant height of millet grown in mulched (M) and not mulched (NM) soils and irrigated every two days with mixed sea-tap waters.

4.2.2 Second season results

In general, the height of three sorghum varieties irrigated with waters of different EC values applied every 2 days and grown on a non-mulched soil significantly increased linearly with increase of time (Table 4.11).

The three sorghum varieties irrigated with mixed water of EC equal to 3.1 gave higher plants than those irrigated with tap water. In the 8^{th} week, Aklomoy, Wad Ahmed and R5 reached heights equal to 59.7, 58 and 53.7 cm, respectively when irrigated with water having 3.1 dS/m. The same varieties in sequence attained heights equal to 53.7, 54.0 and 51.7 cm when irrigated with tap water. However the difference was not significant.

The three sorghum varieties died after the 3^{rd} and 4^{th} week when irrigated with water having EC equal to 9.3 and 5.5 dS/m, respectively. Aklomoy, Wad Ahmed and R5 reached heights of 29.7, 29.3 and 28.3, respectively when irrigated with water of EC equal to 9.3 dS/m and reached heights of 34.0, 34.7 and 32 cm, respectively when irrigated with water of EC equal to 5.5 dS/m

Table 4.11 Effect of period, EC of tap and mixed sea-tap waters and sorghum variety on plant height irrigated at 2- day irrigation interval on non-mulched soils.

EC (dS/m)	Period (week)							
	1	2	3	4	5	6	7	8
Aklomoy								
0.4	29.3	41.0	44.7	46.7	49.0	51.7	51.7	53.7
3.1	28.7	33.3	40.0	46.3	50.7	57.0	57.0	59.7
5.5	31.3	32.3	33.7	34.0	-	-	-	-
9.3	25.0	26.7	29.7	-	-	-	-	-
LSD	7.988	10.313	11.139	13.435	18.579	17.730	18.922	19.28
Prob.	0.381	0.071	0.0585	0.1003	0.8156	0.597	0.4776	0.436
Wad Ahmed								
0.4	29.0	34.3	40.0	43.7	47.3	50.0	52.7	54.0
3.1	27.3	28.7	36.3	41.0	49.7	56.3	56.3	58.0
5.5	31.0	32.7	34.3	34.7	-	-	-	-
9.3	24.3	26.7	29.3	-	-	-	-	-
LSD	6.362	7.19	6.2447	8.129	9.021	13.283	13.283	13.023
Prob.	0.1799	0.1275	0.0253	0.0832	0.5124	0.4862	0.4862	0.4418
R5								
0.4	21.3	27.7	34.3	40/0	46.0	48.0	50.0	51.7
3.1	26.7	34.0	38.7	42.0	45.3	48.3	50.7	53.7
5.5	23.2	26.3	29.3	32.0	-	-	-	-
9.3	23.7	26.7	28.3	-	-	-	-	-
LSD	5.2697	5.803	4.922	4.8938	9.3925	4.6274	4.8972	8.5826
Prob.	0.2156	0.0492	0.0043	0.0055	0.8534	0.8512	0.7247	0.5529

Table 4.12 Effect of period expressed in weeks (W) and variety at designated EC values of tap or mixed sea-tap water on plant height (H) of sorghum irrigated every two days as shown by the following regression trendline (H = b W + a)

EC (dS:m)	b	a	r^2
Aklomoy			
0.4	2.8976	32.760	0.8297
3.1	4.5469	25.754	0.9742
5.5	0.9500	30.450	0.9505
9.3	2.3500	22.433	0.9751
Wad Ahmed			
0.4	3.5786	27.771	0.9645
3.1	4.9119	21.721	0.9676
5.5	1.2700	30.000	0.9435
9.3	2.500	21.767	0.9995
R5			
0.4	4.4214	19.979	0.9435
3.1	3.6262	26.107	0.9677
5.5	2.9400	20.350	0.9990
9.3	2.300	21.633	0.9700

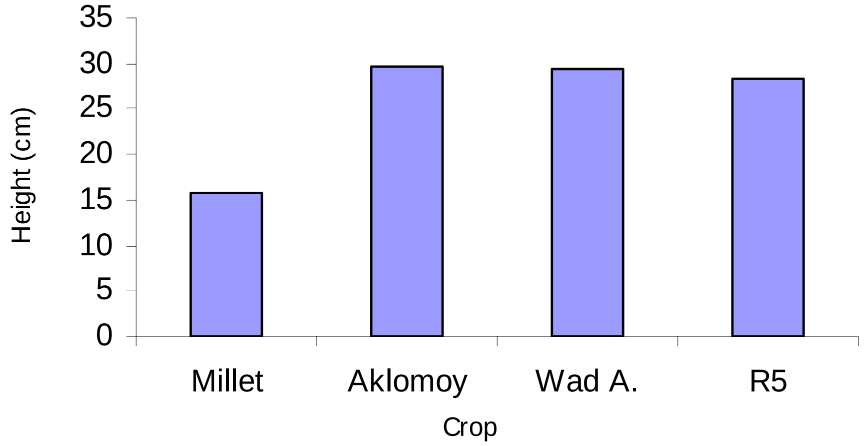

Fig. 4.12. Height of millet and different sorghum varieties irrigated with mixed water of EC equal to 9.3 every 2 days for 4 weeks

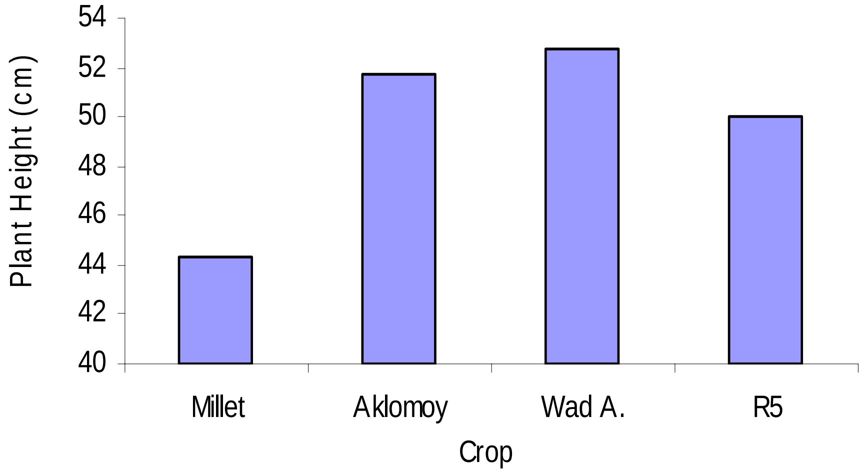

Fig. 4.13. Height of millet and different sorghum varieties irrigated with tap water every 2 days for 7 weeks

4.3 Effect of leaching water on growth plant

4.3.1 Effect of leaching water on Millet

Table 4.13, 4.14 and 4.15 show that the leaching water increased significantly ($P<0.001$) with increased of salinity level in first season. It increased linearly with increase of EC value (Fig.4.14).

Millet plant irrigated with mixed water having EC value 16.6 dS/m died after three weeks of irrigated by it. The EC value of leaching water increased with the increase of EC value of irrigated water.

The following relationship data of leaching water to third week for the various irrigation intervals:

a) 2-day irrigation interval

$r^2 = 0.8741$

b) 4-day irrigation interval

$r^2 = 0.9379$

c) 7-day irrigation interval

$r^2 = 0.9571$

In general, leaching water increased with increase of EC value of irrigation water on mulched and non-mulched soils.

Table 4.13 Added and leached water at 2 days' irrigation interval in first season (Third week).

ECi dS/m	ECd dS/m	ECi/ECd dS/m	Di mm	Dd mm	Dd/Di
0.4	0.6	0.67	292.04		
3.1	6.5	0.48	276.46	26	0.09
5.5	8.8	0.63	321.24	40	0.12
9.3	11.1	0.84	523.72	67	0.13
16.6	16.8	0.99	601.59	67	0.11

Table 4.14 Added and leached water at 4 days' irrigation interval in first season (Third week).

ECi dS/m	ECd dS/m	ECi/ECd dS/m	Di mm	Dd mm	Dd/Di
0.4	0.5	0.80	265.49		
3.1	4.6	0.67	301.59	45	0.15
5.5	8.3	0.66	350.44	68	0.19
9.3	11.8	0.79	571.33	120	0.21
16.6	16.6	1.00	656.28	123	0.19

Table 4.15 Added and leached water at 7 days' irrigation interval in first season (Third week).

ECi dS/m	ECd dS/m	ECi/ECd dS/m	Di mm	Dd mm	Dd/Di
0.4	0.5	0.80	318.58		
3.1	4.3	0.72	263.89	44	0.17
5.5	6.4	0.86	306.64	57	0.19
9.3	8.4	1.11	499.91	134	0.27
16.6	12.1	1.37	574.25	147	0.26

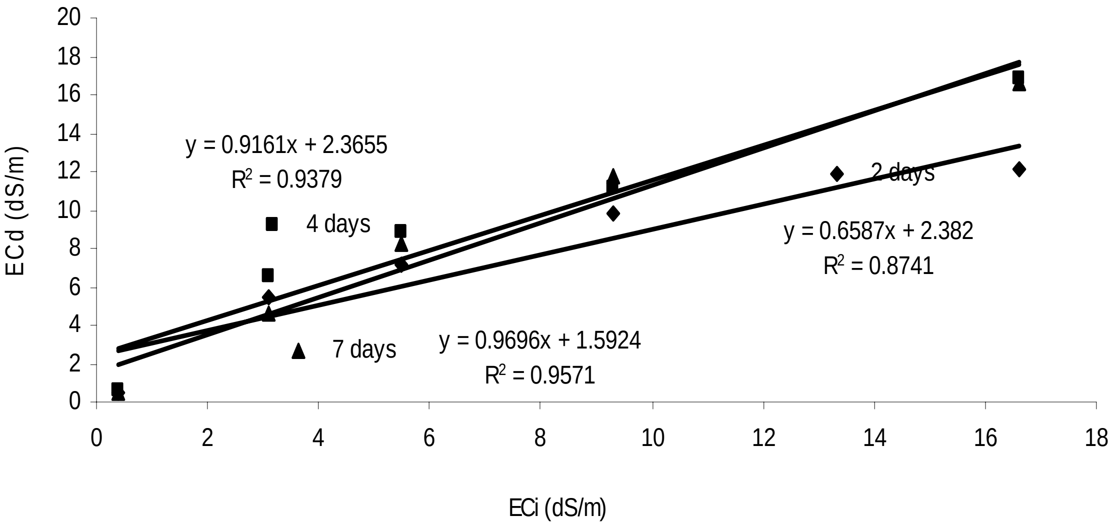

Fig 4.14 The relationship between EC of the irrigation and EC of the leaching water with the irrigation interval up to third week.

4.3.2 Effect of leaching water on Sorghum bicolor

Table. 4.16, 4.17, 4.18 showed that the leaching water increased significantly ($P<0.001$) with increased of salinity level and also with increase of period of growth in second season. The EC value of the leaching water increased linearly with increase of the EC value of irrigated water (Fig.4.15).

Sorghum plant irrigated with mixed water having EC value 9.3 dS/m has higher leaching water than the other EC values, and they died after reaching third week.

The relationship data of leaching water to third week for the various sorghum varieties as the same; no variation between Wad Ahmed, Aklomoy and R5.

$r^2 = 0.9486$

Table 4.16 Added and leached water at 2 days' irrigation in sorghum R5 (Third week).

ECi dS/m	ECd dS/m	ECi/ECd dS/m	Di mm	Dd mm	Dd/Di
0.4	0.5	0.80	336.28		
3.1	5.2	0.60	672.36	86	0.13
5.5	7.0	0.79	778.61	117	0.15
9.3	9.9	0.94	1258.64	193	0.15

Table 4.17 Added and leached water at 2 days' irrigation in sorghum Wad Ahmed (Third week).

ECi dS/m	ECd dS/m	ECi/ECd dS/m	Di mm	Dd mm	Dd/Di
0.4	0.5	0.80	336.28		
3.1	5.2	0.60	672.36	86	0.13
5.5	7.0	0.79	778.61	117	0.15
9.3	9.9	0.94	1258.64	193	0.15

Table 4.18 Added and leached water at 2 days' irrigation in sorghum Aklomoy (Third week).

ECi dS/m	ECd dS/m	ECi/ECd dS/m	Di mm	Dd mm	Dd/Di
0.4	0.54	0.74	336.28		
3.1	5.4	0.57	672.36	81	0.12
5.5	7.1	0.77	778.61	119	0.15
9.3	9.8	0.95	1258.64	202	0.16

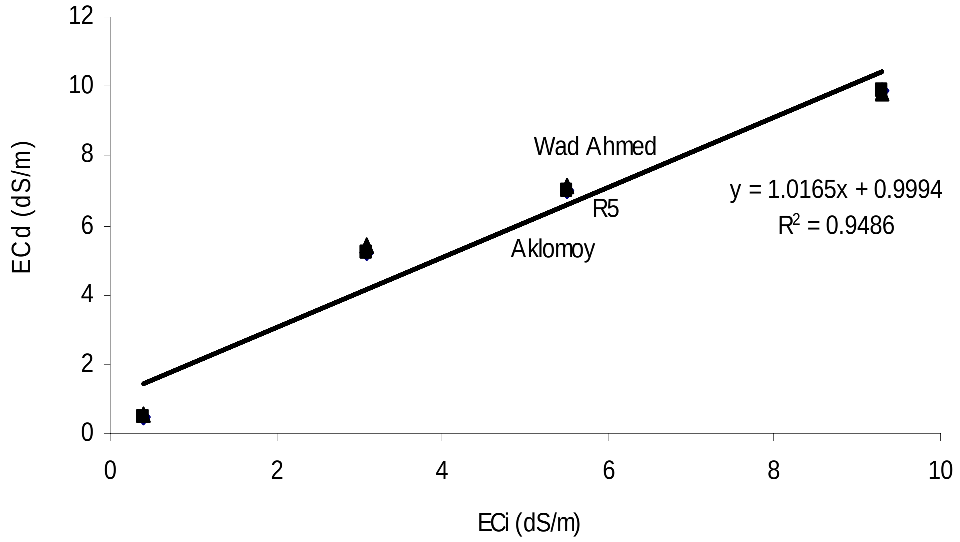

Fig 4.15 The relationship between EC of irrigation and EC of leaching for sorghum varieties

Chapter Five

General Discussion and Conclusions

5.1 Germination

In general and for all crops, the results showed significant ($P < 0.001$) linear increase in germination percentage (G %) with increase in time (Td, days) at all salinity levels of the irrigation water (ECi). This indicates that for good or bad quality water, i.e. at a given ECi, time is the main determinant of germination. However, millet germination started on the third and fourth day when irrigated with waters having ECi equal to 9.3 and 16.6 dS/m, respectively. Furthermore, germination of Aklomoy started on the fourth day and that of Wad Ahmed and R5 started on the third day when irrigated with water having ECi equal to 9.3 dS/m. As an example, millet irrigated with ECi equal to 16.6 dS/m, gave the following relationship:

$$G\ \% = 9.0\ Td - 20.3 \qquad (r^2 = 0.940)$$

In this case germination was delayed for three days explaining the negative intercept depicted in the equation. This relationship indicates that 94% of the variation of germination is due to time.

The results also showed highly significant ($P < 0.001$) linear decrease in germination percentage of all crops with increase in ECi of the irrigation water. After 8 days, the relationships were as follows:

Millet: $G\ \% = -3.1\ ECi + 92.3 \quad (r^2 = 0.939)$

Sorghum (Aklomoy): $G\ \% = -6.2\ ECi + 104.8 \quad (r^2 = 0.910)$

Sorghum (Wad Ahmed): $G\ \% = -2.9\ ECi + 96.4 \quad (r^2 = 0.918)$

Sorghum (R5): $G\ \% = -3.6\ ECi + 96.2 \quad (r^2 = 0.859)$

The four varieties yielded qualitatively similar linear relationships with regard to the impact of salinity of the irrigation water on germination. The relatively high coefficients of determination indicate that after a given period ECi is the main determinant of germination. The threshold ECi at which crops did not germinate was 16.6 dS/m for millet and 9.3 dS/m for Sorghum.

The tolerance of the various crop varieties at the germination stage was assessed by two indicators, namely the rate of decrease of G % per unit ECi, i.e. the slope of the linear relationships and G % at ECi = 9.3 dS/m. The rate of decrease of germination percentage per unit ECi was 3.1 for millet, 6.2 for Aklomoy, 2.9 for Wad Ahmed and 3.6 for R5. Assuming this rate as an indicator of the sensitivity of crop to salinity the order of crop tolerance to salinity may be arranged as follows:

Wad Ahmed > Millet > R5 > Aklomoy

Using the empirical equations for the various crops, the G % at ECi equal to 9.3 dS/m was 63.8 for millet, 46.9 for aklomoy, 69.3 for Wad Ahmed and 62.5 for R5. These results reflect the same order of salinity tolerance as shown above.

Salinity increases the ionic strength of the irrigation water reduces its activity and thereby limits water and nutrient uptake by seeds and eventually delays seed germination. The reduction of seed germination by salinity agrees with the findings of several other research workers (Pojakoff-Mayber and Gale, 1975; Volkmar *et al*., 1998; Maathius and Amtmann, 1999, Niknam and McCombo, 2000)

5.2 Plant height

In general, for all crops and irrigation waters and intervals, plant height increased significantly with increase of growth period up to a time limit governed by the salinity level of the irrigation water.

In the first season, millet growth continued to the 7^{th} week when irrigated at 2-day or 4-day interval using waters with ECi equal to 0.4 dS/m or 3.1 dS/m; but the growth ceased and the plants died in the 5^{th}, 4^{th}, and 3^{rd} week when irrigated at similar intervals with waters having ECi equal to 5.5, 9.3 and 16.6 dS/m, respectively. The periods of growth were the same for the 7-day irrigation interval, except that for waters having ECi equal to 5.5 dS/m, the growth continued for one day more before collapsing.

At the three irrigation intervals, the results showed significant quadratic decrease in millet height with increase of ECi. Using the generated empirical relations in the results section, the height of millet, irrigated every 2, 4, and 7 days with a water of ECi equal to 3 dS/m was 21, 22 and 24 cm, respectively. For mixed water of ECi equal to 5 dS/m, the height for the three irrigation intervals in sequence was 18, 20 and 22 cm. The growth was stunted by salinity. The empirical relationship for millet irrigated every two days was as follows:

$H = 0.0665\ ECi^2 - 1.7494\ ECi + 25.5 \quad (r^2 = 0.9852)$

All sorghum varieties failed to grow in mixed water having ECi equal to 16.6 dS/m. The impacts of period and ECi on the height of the three sorghum varieties were qualitatively similar to those obtained for millet. The following empirical relationships for sorghum plant height (H, cm), irrigated every 2 days, versus ECi for the third week were obtained:

Aklomoy

$H = 0.0802\ ECi^2 - 2.5229\ ECi + 46.0 \quad (r^2 = 0.9852)$

Wad Ahmed

$H = -0.0035\ ECi^2 - 1.1432\ ECi + 40.3 \quad (r^2 = 0.9939)$

R5

$H = -0.0917\ ECi^2 - 0.0189\ ECi + 35.6 \quad (r^2 = 0.0.5637)$

Using these equations and ECi equal to 3 dS/m, the plant heights were 21 cm for millet, 34.7 cm for R5, 36.8 cm for Wad Ahmed and 39.1 cm for Aklomoy. The order of tolerance of the various crop varieties were in the following order:
Aklomoy > Wad Ahmed > R5 > millet

It is evident that the order of tolerance after 3 weeks of growth was different from that at the germination stage. It is known that crop tolerance to salinity varies with stage of plant growth (Bernstein, 1964).

Salinity reduces plant growth by limiting water and nutrient uptake and ion toxicity. Salinity stress was found to reduce cell elongation by diverting energy to sustain osmotic adjustment (Volkmar *et al.*, 1998). Ahmed (2007) found that the main ions in the Red Sea water were Na^+ and Cl^-, which are known to be toxic to some fruit trees and beans. They may be toxic to millet and sorghum; but this remains to be proved by a more focused investigation. Sodium chloride was found to inhibit plant growth of many species (Daoud *et al.*, 2004).

In general, mulching did not significantly affect plant growth, which may be due to limited exposed pot area and other factors.

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Appendix 1 Some meteorological data, reference evapotranspiration (ETr), crop factor (Kc), and crop evapotranspirationfor (Etc) for the first season experiment.

Month	T°c	n	N	R_a	R_s	ETp	Kc	ETc
January	22.0	10.0	11.3	12.3	8.5	6.3	0.433	2.73
February	24.5	10.1	11.6	13.6	9.3	7.5	0.816	6.12
March	27.2	9.8	12.0	14.9	9.8	8.5	1.1	9.35
April	31.3	10.3	12.5	15.7	10.4	10.0	1.086	10.86

T: mean temperature, n: sunshine hours, N: daily maximum possible sunshine hours.

Appendix 2 Some meteorological data, reference evapotranspiration (ETr), crop factor (Kc), and crop evapotranspirationfor (Etc) for the second season experiment.

Month	T°c	n	N	R_a	R_s	ETp	Kc	ETc
June	34.0	9	13	15.7	9.4	9.6	0.8	7.68
July	32.5	8	12.9	15.7	8.8	8.7	0.8	6.96
August	31.4	7.9	12.6	15.7	8.8	8.5	1.15	9.78
Sept.	32.3	8.4	12.2	15.1	9.0	8.8	1.15	10.12
Oct.	31.7	9.6	11.8	14.1	9.3	9.0	0.55	4.95

Abbreviations as in Appendix A1.

Appendix 3 Monthly irrigation water requirement (Wri) for millet and the quantity of water to be applied per irrigation for first season.

Month	Sea-Tap water Ratio	ECi dS/m	ETr	ETc	LF	1-LF	Wri,mm /day	Wri,ml /day	Quantity of water		
									2 days	4 days	7 days
January	1:20	3.1	6.3	2.73	0.13	0.87	3.1	142	284	568	994
	1:10	5.5	6.3	2.73	0.25	0.75	3.6	165	330	660	1155
	1:5	9.3	6.3	2.73	0.54	0.46	5.9	269	538	1076	1883
	1:2.5	16.57	6.3	2.73	1.4	0.4	6.8	309	618	1236	2163
	0:1	0.4	6.3	2.73	0.0						
Feb.	1:20	3.1	7.5	6.12	0.13	0.87	7	318	636	1272	2226
	1:10	5.5	7.5	6.12	0.25	0.75	8.2	369	738	1476	2583
	1:5	9.3	7.5	6.12	0.54	0.46	13.3	602	1204	2408	4214
	1:2.5	16.57	7.5	6.12	1.4	0.4	15.3	692	1384	2768	4844
	0:1	0.4	7.5	6.12	0.0						
March	1:20	3.1	8.5	9.35	0.13	0.87	10.7	486	972	1944	3402
	1:10	5.5	8.5	9.35	0.25	0.75	12.5	564	1128	2256	3948
	1:5	9.3	8.5	9.35	0.54	0.46	20.5	920	1840	3680	6440
	1:2.5	16.57	8.5	9.35	1.4	0.4	23.4	1059	2118	4236	7413
	0:1	0.4	8.5	9.35	0.0						
April	1:20	3.1	10.0	10.86	0.13	0.87	12.5	565	1130	2260	3955
	1:10	5.5	10.0	10.86	0.25	0.75	14.5	655	1310	2620	4585
	1:5	9.3	10.0	10.86	0.54	0.46	23.6	1068	2136	4272	7476
	1:2.5	16.57	10.0	10.86	1.4	0.4	27.2	1231	2462	4924	8617
	0:1	0.4	10.0	10.86	0.0						

LF = Leaching Fraction

Appendix 4 Monthly irrigation water requirement (Wri) for millet and the quantity of water to be applied per irrigation for second season.

Month	Sea-Tap water Ratio	ECi dS/m	ETr	ETc	LF	1-LF	Wri,mm /day	Wri,ml /day	Quantity of water 2 days
June	1:20	3.1	9.6	7.68	0.12	0.88	8.73	394.74	789.47
	1:10	5.5	9.6	7.68	0.24	0.76	10.11	457.13	914.27
	1:5	9.3	9.6	7.68	0.53	0.47	16.34	738.83	1477.66
	0:1	0.4	9.6	7.68	0.0				
July	1:20	3.1	8.7	6.96	0.12	0.88	7.91	357.62	715.23
	1:10	5.5	8.7	6.96	0.24	0.76	9.16	414.08	828.17
	1:5	9.3	8.7	6.96	0.53	0.47	14.81	669.58	1339.16
	0:1	0.4	8.7	6.96	0.0				
August	1:20	3.1	8.5	9.77	0.12	0.88	20.79	502	1004
	1:10	5.5	8.5	9.77	0.24	0.76	12.86	581.26	1162.53
	1:5	9.3	8.5	9.77	0.53	0.47	11.10	939.92	1879.83
	0:1	0.4	8.5	9.77	0.0				
Sept.	1:20	3.1	8.8	10.12	0.12	0.88	11.50	519.98	1039.97
	1:10	5.5	8.8	10.12	0.24	0.76	13.32	602.09	1204.17
	1:5	9.3	8.8	10.12	0.53	0.47	21.53	973.59	1947.17
	0:1	0.4	8.8	10.12	0.0				